Estimating tidal transports from geomagnetic satellite observations

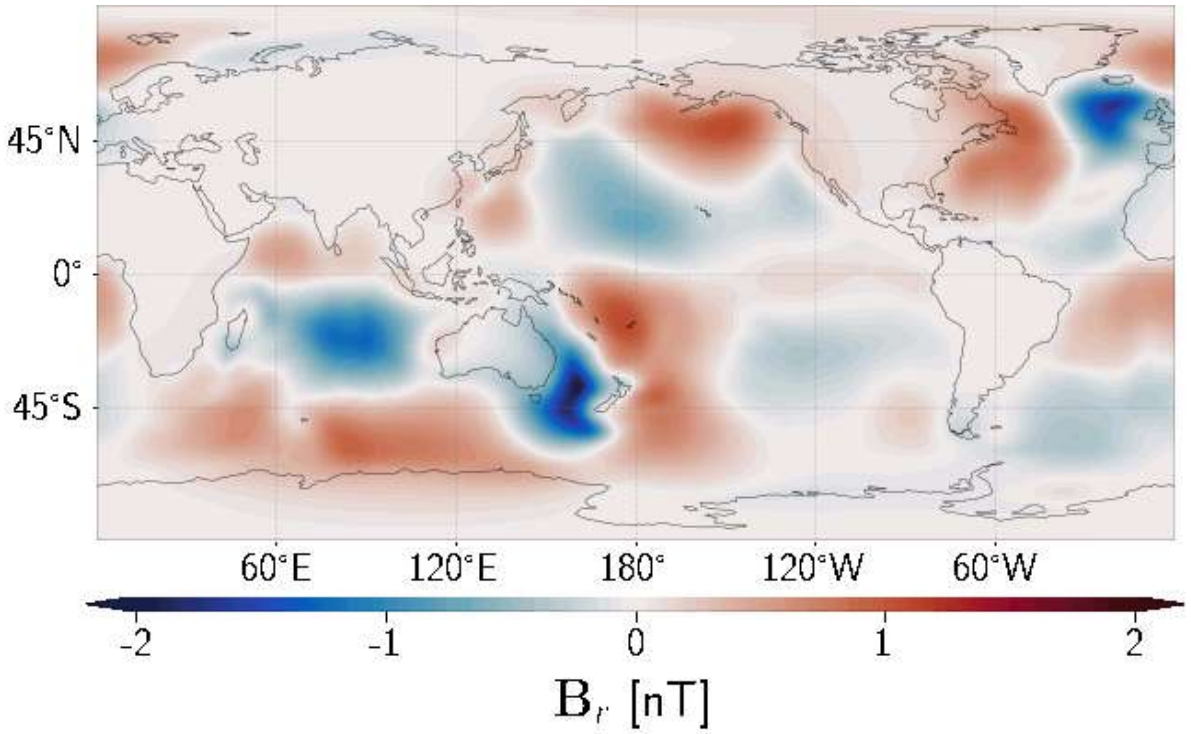
Aaron Hornschild[1], Jan Saynisch-Wagner[1], Julien Baerenzung[2] and Maik Thomas [3]

[1]*German Research Centre for Geosciences, Potsdam Germany*
[2] *TU Technical University Berlin,Berlin, Germany*
[3] *Freie Universität Berlin, Berlin, Germany*

Swarm 10 Year Anniversary & Science Conference 2024
8 - 12 April, Copenhagen

Tidal ocean-induced magnetic signals

Tidal-induced magnetic signal (M_2)



- **Movement of conductive seawater** through the Earth's magnetic generates electric currents and **induces** secondary **magnetic signals**

Swarm observations of the ocean-induced magnetic fields as source of information about the ocean system

EM signal dependencies

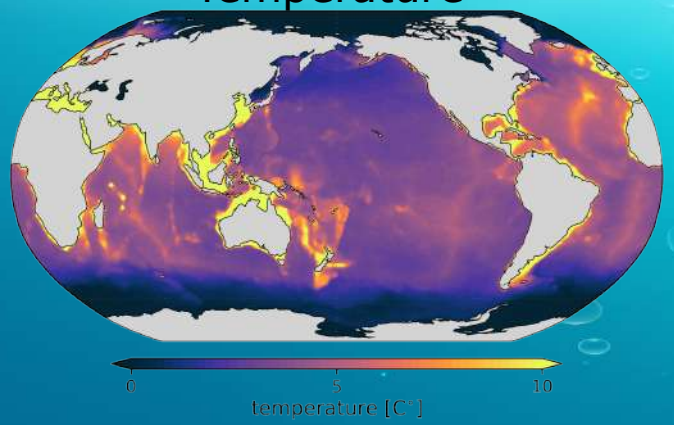
Electric source: $\mathbf{J} = \sigma \cdot (\mathbf{U} \times \mathbf{B}_{\mathbf{earth}})$

Conductivity σ

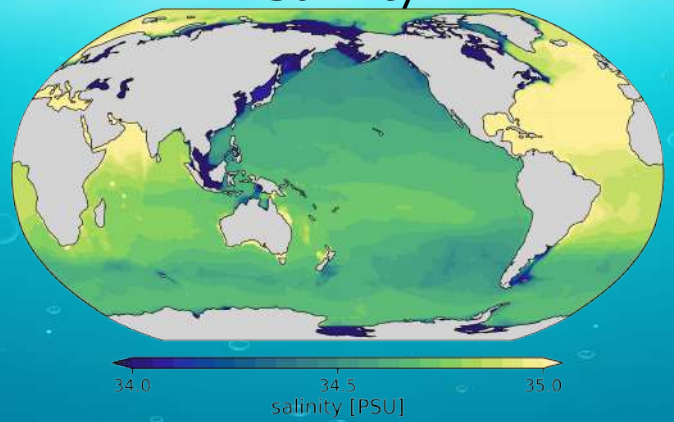
Transport $\mathbf{U}$

whole water column

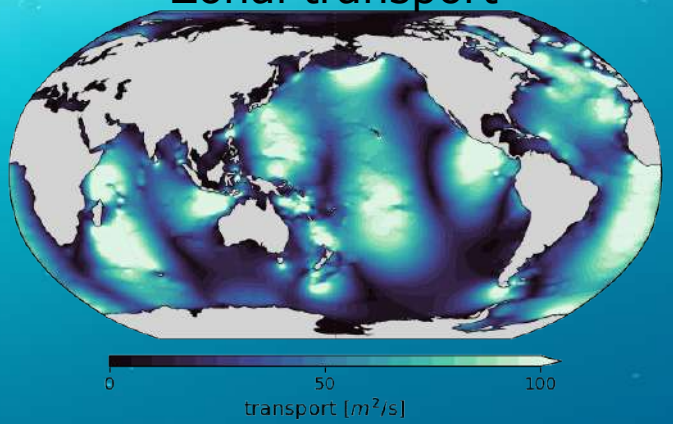
Temperature



Salinity



Zonal transport



- Used to derive the ocean heat content

EM signal dependencies

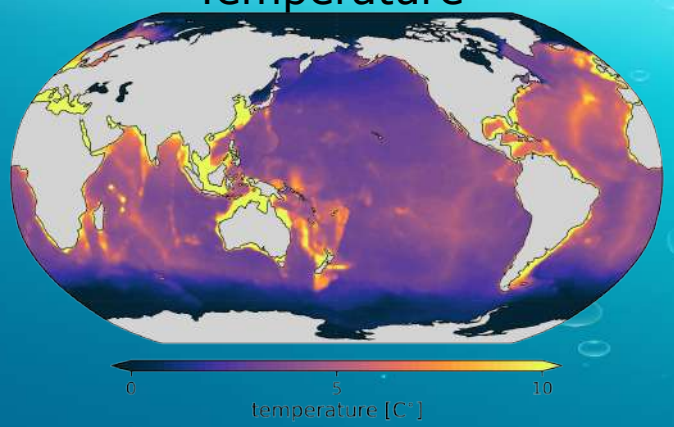
Electric source: $\mathbf{J} = \sigma \cdot (\mathbf{U} \times \mathbf{B}_{\mathbf{earth}})$

Conductivity σ

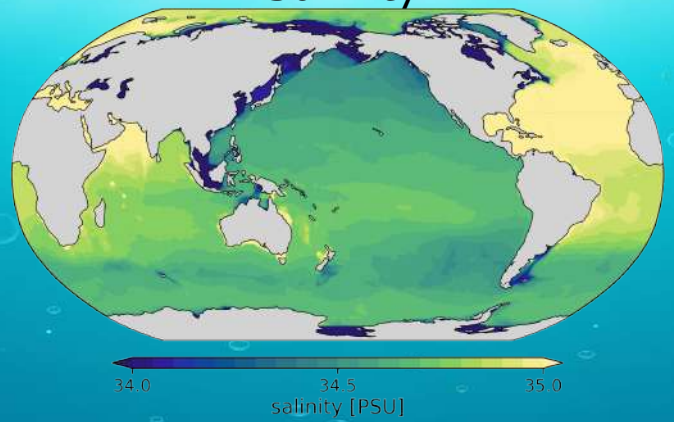
Transport $\mathbf{U}$

whole water column

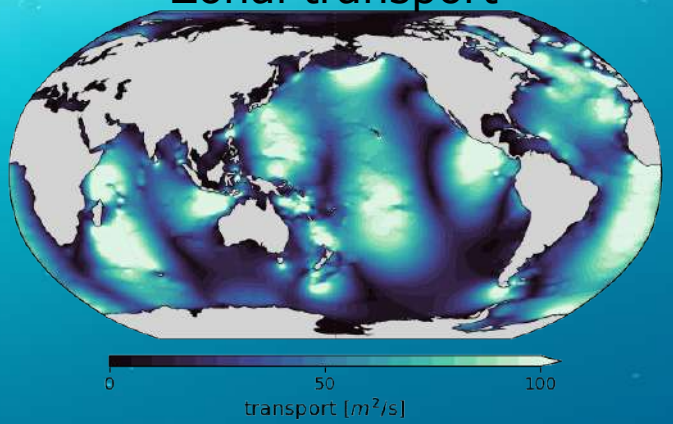
Temperature



Salinity



Zonal transport

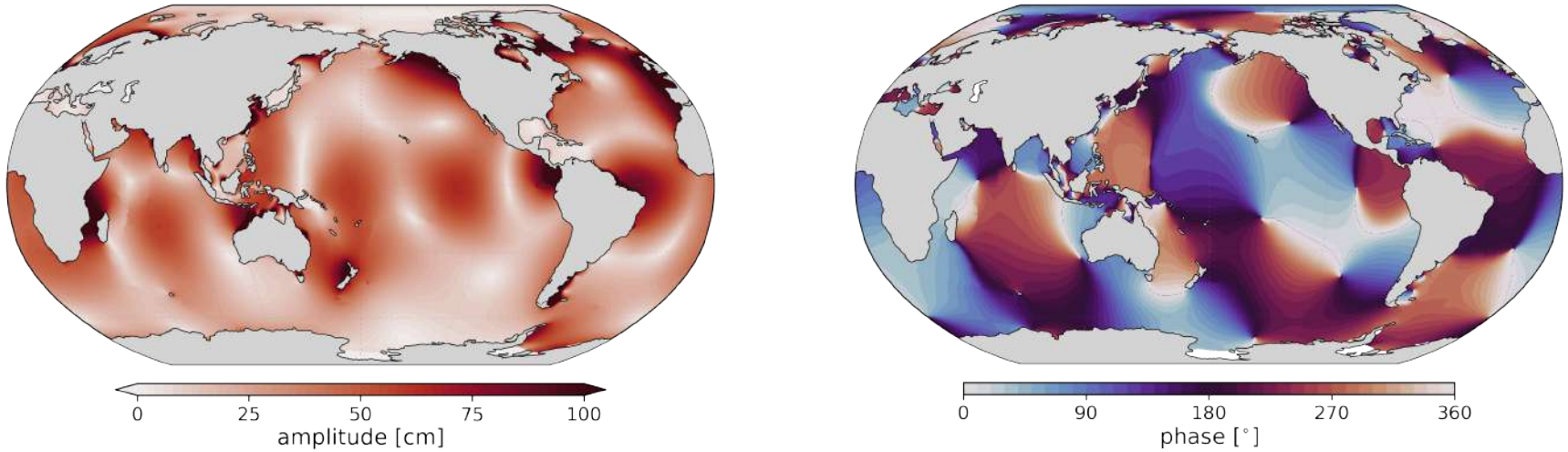


- Used to derive the ocean heat content
- Inversion?

Tidal elevations by satellite altimetry

- Ocean tides are a major driver of ocean global oceanic mixing
- Global observation of the tides are so far based on **satellite altimetry**
- Tidal elevations are of high interest and globally well observed

Tidal elevation of M_2



Ocean tidal data assimilation model HAMTIDE

- However, deep-ocean **tidal currents are difficult to observe** and not well know

Poloidal-toroidal decomposition

- Tidal transports are expressed in poloidal and toroidal components $\mathbf{U} = \mathbf{U_P} + \mathbf{U_T}$

Poloidal component (U_P)

- Directly linked to tidal elevation

$$i\omega\xi = -\nabla_h \mathbf{U_P}$$

with the tidal elevation: $\xi = \hat{\xi} e^{i\omega t}$

- **Can be *easily* observed by satellite altimetry**

Toroidal component (U_T)

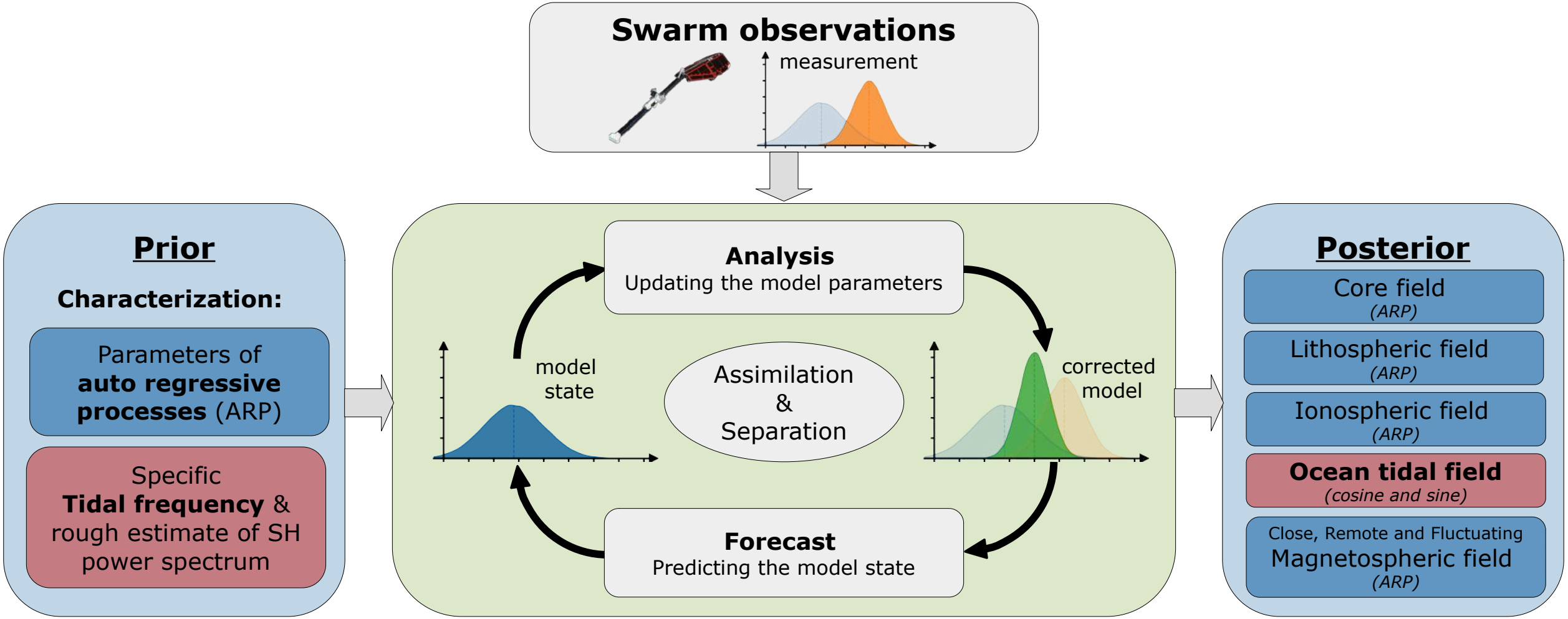
- Divergence free component
- Linked to dissipation by friction, mixing, loading and self-attraction
- Parameters must be well-known
- **Can be *hardly* observed by satellite altimetry**

In contrast:

- Magnetic signals are **directly sensitive** to tidal transports
- Requires only very loose prior assumptions

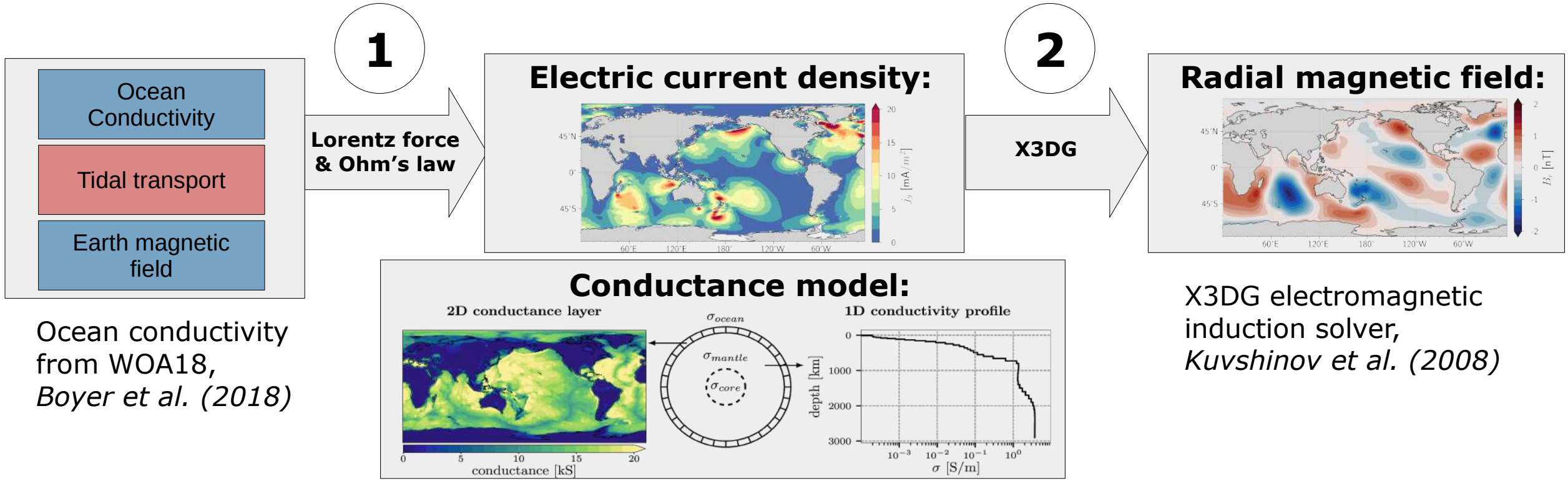
Kalman filter-based assimilation

- Using Kalman filter inversion: geomagnetic field model **KALMAG** (*Baerenzung et al., 2020,2022*)



Magnetic field observation operator

- Incorporate invertible **observation operator** for tidal transports into Kalmag
- Magnetic field operator consists of two steps:



Ocean conductivity from WOA18, *Boyer et al. (2018)*

Mantle conductivity, *Grayver et al. (2017)*

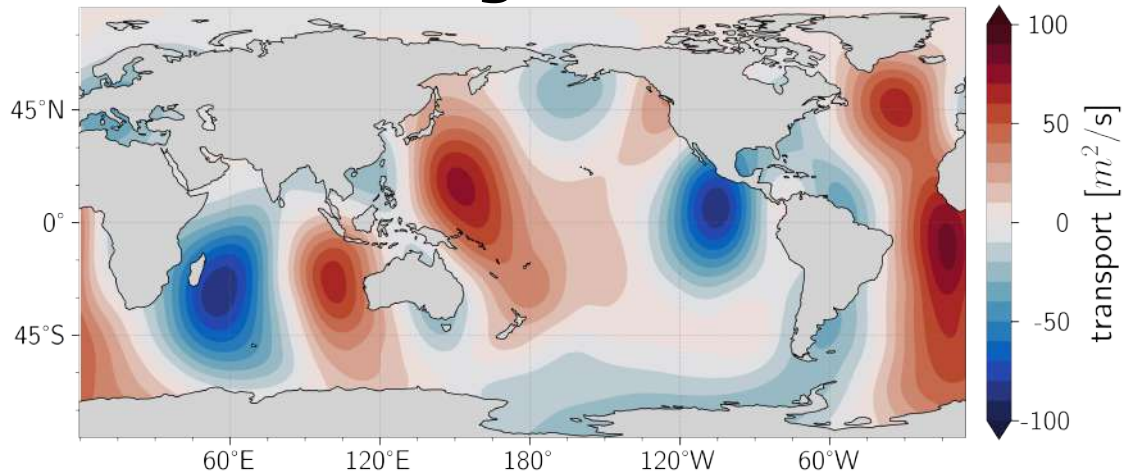
X3DG electromagnetic induction solver, *Kuvshinov et al. (2008)*

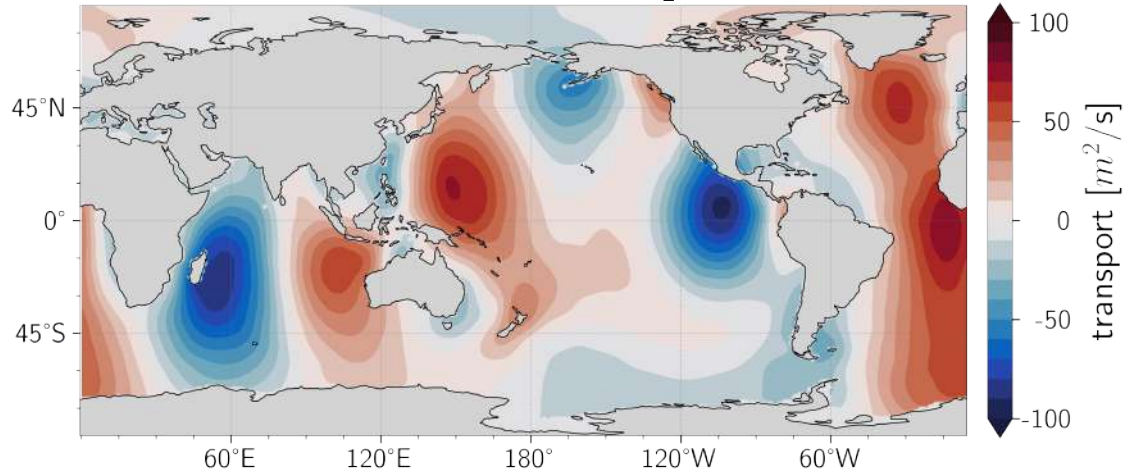
Estimated tidal transport (M_2)

- Kalmag-inversion of the ***poloidal transport*** *(real part)* from Swarm satellite observations:

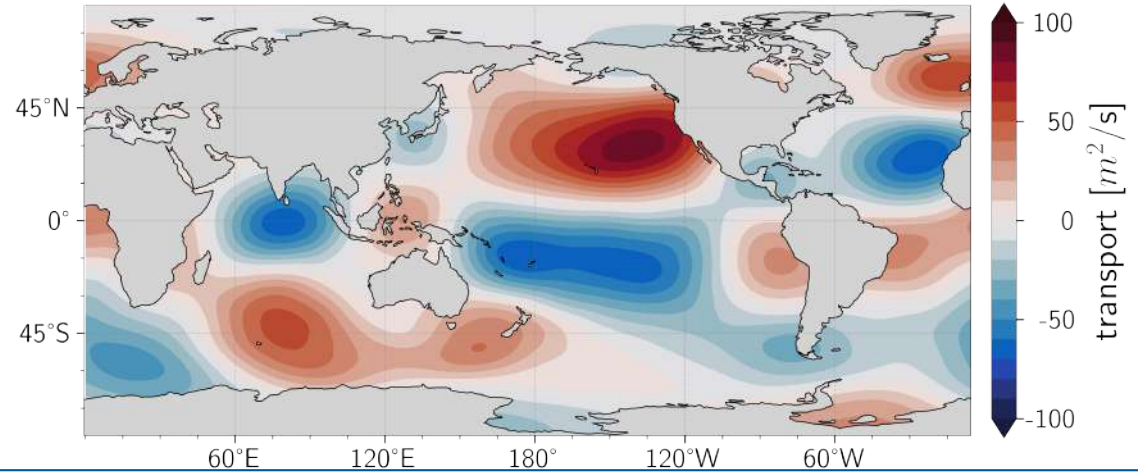
Kalmag estimate: | **HAMTIDE comparison:**

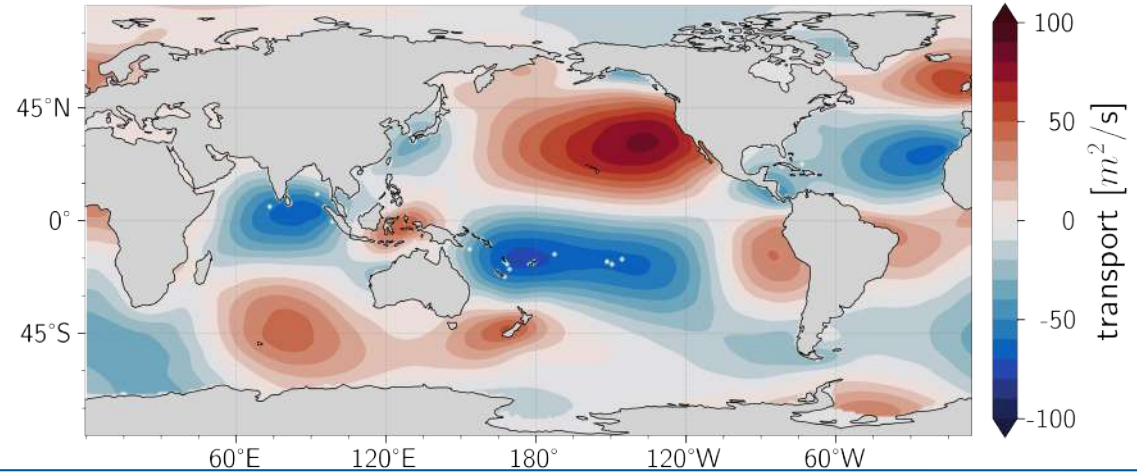
Zonal:





Meridional:



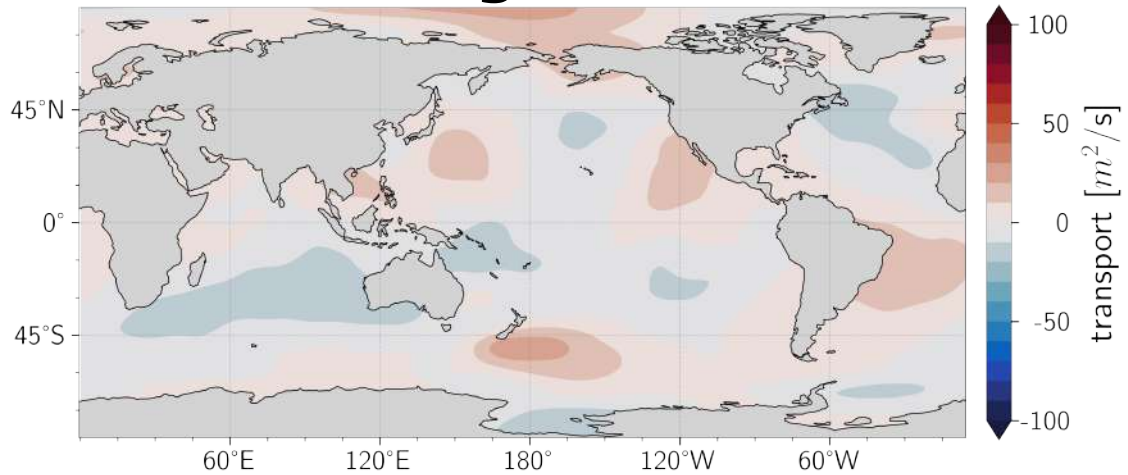


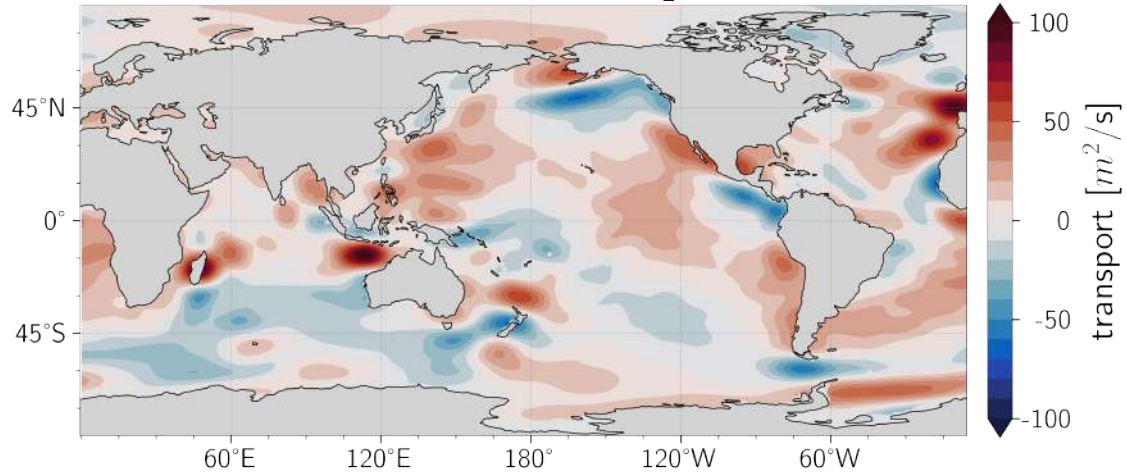
Estimated tidal transport (M_2)

- Kalmag-inversion of the ***toroidal transport*** *(real part)* from Swarm satellite observations:

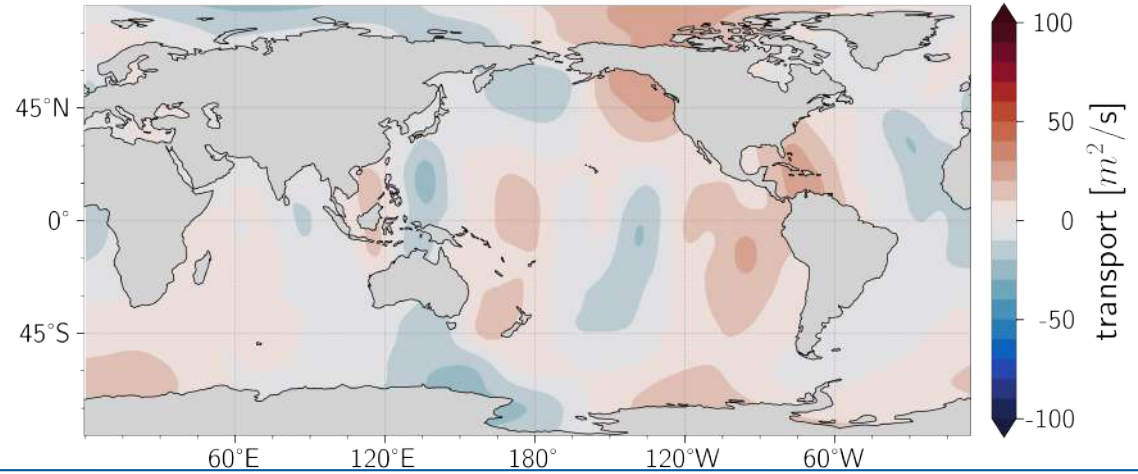
Kalmag estimate: | **HAMTIDE comparison:**

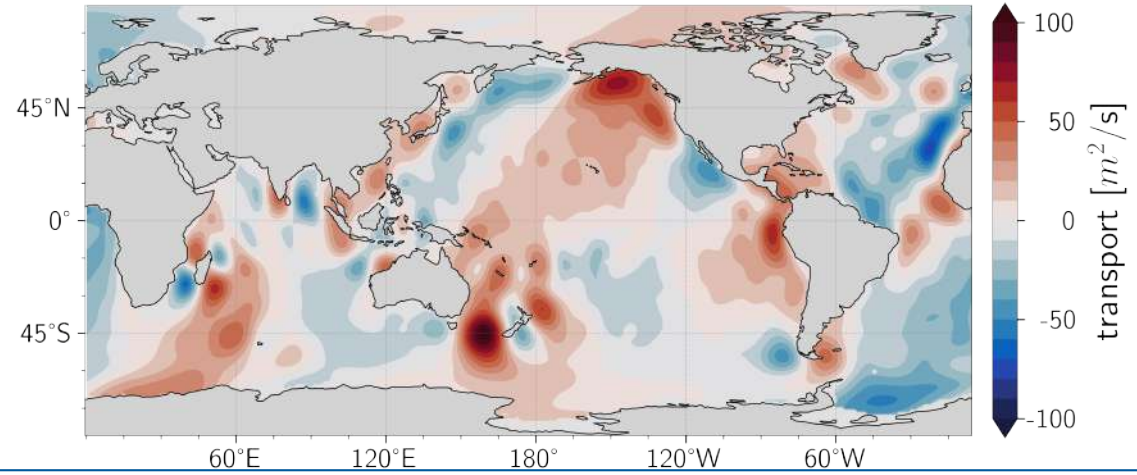
Zonal:





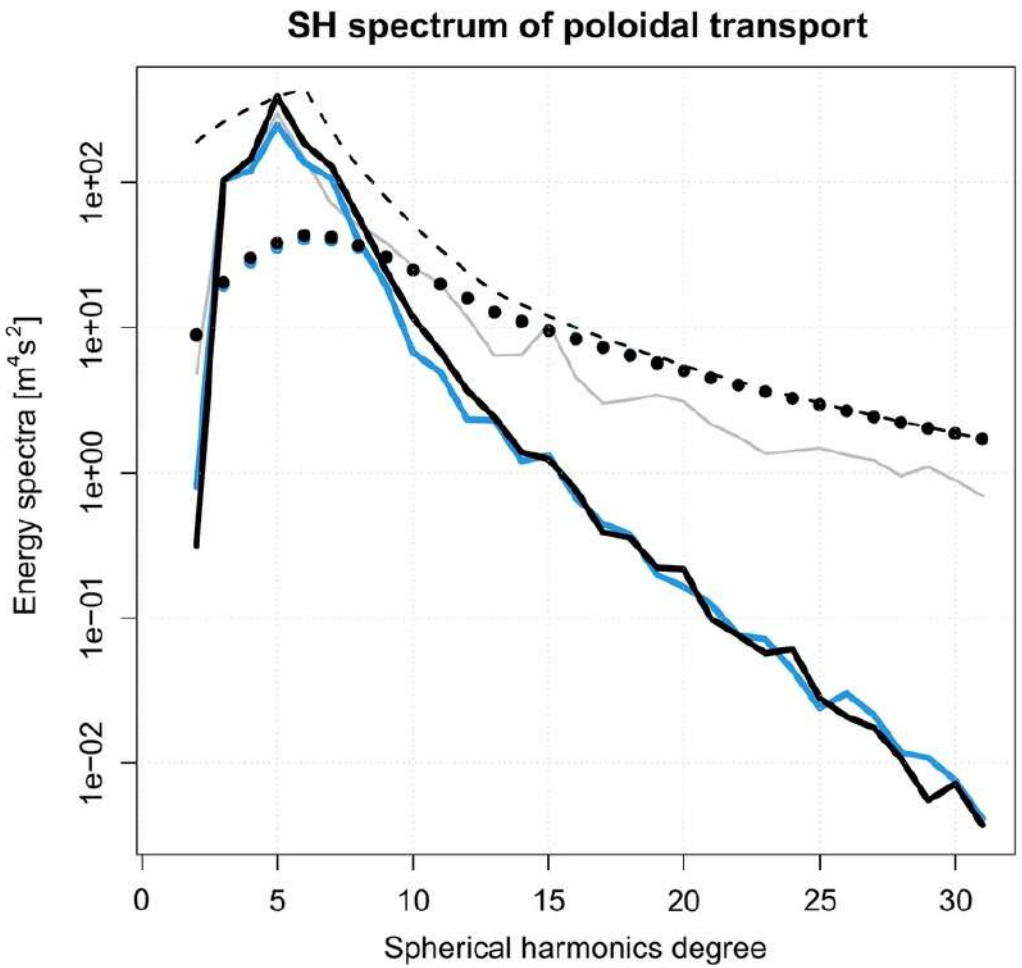
Meridional:

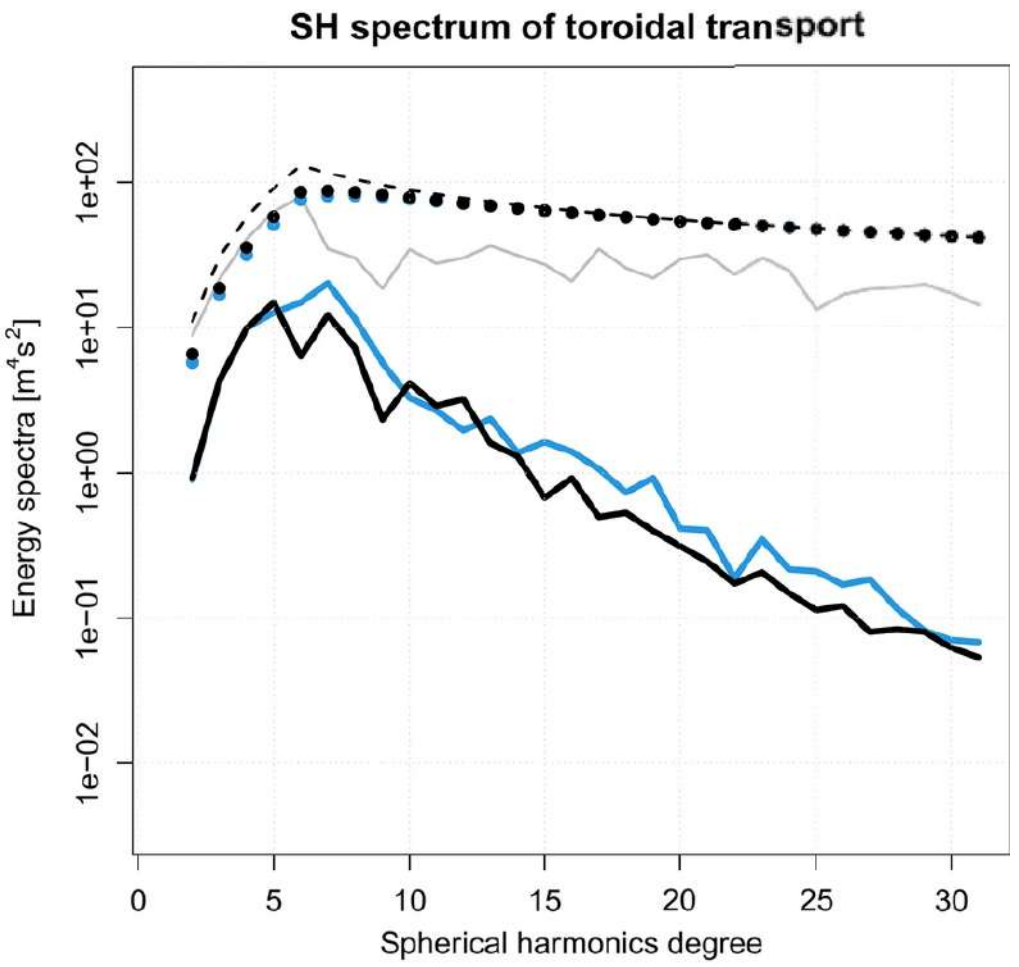


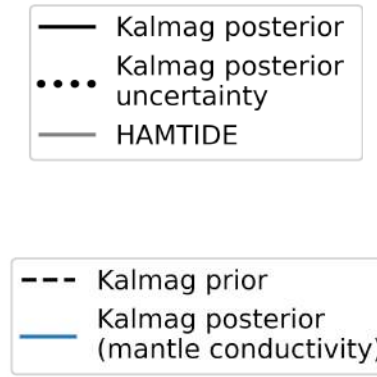


Power spectrum of tidal transport

- Spherical harmonics (SH) power spectrum of M_2 tidal transports:





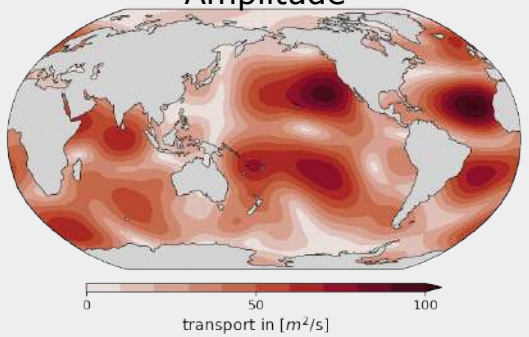


Summary & Conclusion

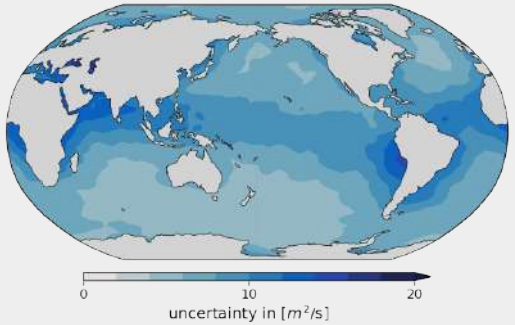
- We inverted Swarm satellite magnetometer data for tidal transports
- We used a Kalman filter (Kalmag) for successful inversion
- Inversion relies on very few prior information

- Poloidal transport are recovered well, toroidal not

Amplitude

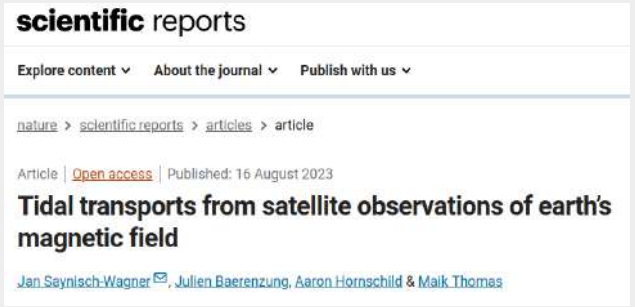


Uncertainty

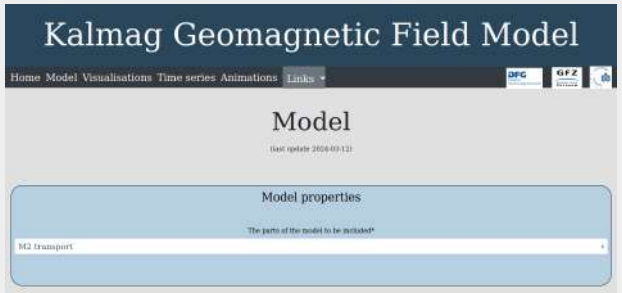


- Mantle conductivity is minor source of error
- Ionosphere plays crucial role

- Published: *Saynisch-Wagner et al. (2023)*



- Available: *https://ionocovar.agnld.uni-potsdam.de/Kalmag/*



Thank you for your attention!